X-621-72-103
PREPRINT

NASA TM X- 65878

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Prepared for presentation at the XV meeting of COSPAR, Madrid, Spain
Paper f.45

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A global empirical model for magnetically quiet conditions has been developed to describe longitudinally averaged OGO-6 N_2, O, and He densities (in the altitude range 400 to 600km) by means of an expansion into spherical harmonics. The accuracy of the analytic description is of the order of the experimental error, thus providing an excellent representation of the satellite observations. Some of the results are summarized. (1) The annual asymmetric component in N_2 density corresponds to an increase of about 400°K between winter and summer poles, which is about a factor of three greater than in the Jacchia model. However, the corresponding oxygen component at satellite altitudes reflects an increase between winter and summer comparable to that in the Jacchia model; this implies that at 120km atomic oxygen increases by more than a factor of two between summer and winter poles. (2) The amplitude of the symmetric semi-annual component in N_2 is larger at the poles than the equator. At the poles the N_2 variation corresponds to a temperature decrease of about 70°K from mid-April to mid-July. (3) At low latitudes the daily temperature maximum occurs close to 16 hours local time, nearly in agreement with radar backscatter observations.

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A GLOBAL EMPIRICAL MODEL OF THERMOSPHERIC COMPOSITION BASED ON OGO-6 MASS SPECTROMETER MEASUREMENTS

Until recently, the bulk of the data available for determining the global behaviour of neutral density in the thermosphere has consisted of total density measurements obtained from satellite drag. Variations in composition can not be uniquely determined from these data and the atmospheric models[1, 2] based on satellite drag have, until recently, generally assumed diffusive equilibrium with fixed boundary densities at 120km.

This paper reports on some aspects of the global behaviour of N_2, O, and He as determined from data obtained with the neutral mass spectrometer carried aboard the OGO-6 satellite. This satellite was launched on June 5, 1969 into an 82° inclination orbit with a 398km perigee and 1100km apogee. The data cover the time period June 27, 1969 to June 22, 1970 during which time data were obtained in the altitude range between perigee and 600km (800km for He). In order to study the behaviour of the thermosphere independent of longitude and universal time effects[3, 4] the globe was divided into 5° latitude bands (with a further subdivision near the poles into south and north bound passes) and data falling within each band were averaged over a 24 hour (universal time) period. Data from days which had an Ap index greater than 5 were excluded in order to minimize magnetic activity effects.[5]

Two different schemes have been used to describe the data. First, the longitudinal averages have been fit with a formula based on a spherical harmonic expansion (in geographic latitude - local time coordinates) in which the composition is described in terms of density variations at 450km with an altitude dependence assuming isothermal conditions at any given time. The expansion includes local time independent, diurnal, and semidiurnal terms and the coefficients have been written as the sums of terms representing the annual, semiannual, solar flux, and magnetic activity variations. The temperature used in the calculation was determined from the N_2 data in a manner to be described shortly, but it is in any case not critical to determining 450km densities as this altitude is near the average altitude of the measurements. A total of 33 parameters was determined by a least squares fit to the data for each constituent. The average error of the fit was 20% for N_2 (about twice the experimental error) and 10% for He and O (about equal to the experimental error).

A second approach used to describe the measured densities was analogous to the method employed in the Jacchia J65 static diffusion model.(1) With the density of N_2 fixed at 120km, the exospheric temperature necessary to calculate the measured densities was determined using analytic density profiles suggested by Walker.(6) The temperature derivation was based on the N_2 density, rather than O or He, because this species is theoretically closest to being in diffusive equilibrium.(7) However, the average temperature needed to fit the measurements is not arbitrary, as the measurements are made at different altitudes, and there is an average temperature which will fit the data best. Details of the global variation of temperature cannot, however, be obtained with much significance from the scale height information. The procedure followed was to fix the

120km N_2 density, fit the measured densities using a spherical harmonic formula for exospheric temperature variation analogous to that used for the 450km density variations, and allow the temperature gradient at 120km to be an additional free parameter so that the average exospheric temperature and density would be consistent with the measurements. By using the model temperatures determined from N_2, the average densities and variations at 120km needed to reproduce the measurements of O and He were determined. It must be kept clearly in mind that although this model represents the measured data quite well, the densities at 120km are only inferred on the basis of the diffusive equilibrium assumption. However, the variations in composition at 120km are a convenient way of illustrating departures from fixed boundary diffusive equilibrium models and to the extent that diffusive equilibrium holds, the O to N_2 and He to N_2 ratios inferred at 120km are relatively independent of errors in the derived exospheric temperature.

The global average densities at 450km (average $F_{10.7} = 150$, $Ap = 3.5$), determined as described above, are 2.52×10^6 cm^{-3} for N_2, 6.42×10^7 cm^{-3} for O, and 3.55×10^6 cm^{-3} for He. Assuming an N_2 density at 120km of 3×10^{11} cm^{-3} and a temperature of 355°K the inferred densities at 120 km are 8.81×10^{10} cm^{-3} for O, and 3.20×10^7 cm^{-3} for He. The average exospheric temperature was 1116°K. The S value in the temperature profile(6) was 0.021. In discussing particular density variations, the results will be given in terms of departures from the above averages.

DIURNAL AND SEMIDIURNAL COMPONENTS

The variation of density with local time at the equator for equinox conditions is shown in Figure 1. At 450km the N_2 density has a maximum at 15.6 hours, the O density at 14.9 hours and the He density at 10.2 hours. The phase of the O density maximum is not significantly later than that in the J65 model. As compared to the J65 model, the later temperature phase and larger maximum to minimum ratio is in agreement with incoherent scatter observations.[8] The amplitudes of the N_2 and O diurnal density variations are in agreement with the J65 model and the small (statistically insignificant) inferred O density variation at 120km indicates that the measured 450km N_2 and O densities are reasonably consistent with a fixed boundary diffusive equilibrium model. The morning maximum for He densities and the systematic change in phase from N_2 to O to He, however, indicate that the thermosphere may not be in complete diffusive equilibrium and the measured trend is consistent with predictions of dynamic effects due to winds.[7]

ASYMMETRICAL ANNUAL COMPONENTS

The seasonal variations in density lead to the latitudinal density profiles seen in Figure 2 for solstice conditions. The measured oxygen density variation at 450km is comparable to that in the J65 model, but the N_2 density variation is about three times larger. Thus, contrary to the situation for the diurnal variations, the relative variation of N_2 and O densities shows a striking departure from a fixed boundary diffusive equilibrium model and the inferred 120km oxygen densities show a winter density enhancement of 2.4 times over summer values. The possibility of a winter oxygen enhancement has been inferred from ionospheric data[9, 10] and a similar trend has been recently deduced from a combination of drag and mass spectrometer data.[11] The greater exospheric temperature variation, from winter to summer pole, deduced from the N_2 densities is in the right direction to resolve a recent[12] objection to explaining the F-region seasonal anomaly by changes in the oxygen to nitrogen ratio.

The measured helium densities clearly reflect the winter helium bulge,[13, 14] however, the inferred helium density variation at 120km is about double that given in a recent Jacchia model.[2] The latitude profile in the summer hemisphere is not as well defined by the OGO-6 measurements as in the winter hemisphere because of a lack of sensitivity, but the indicated gradient is consistent with measurements from Explorer 32.[15]

The latitudinal-seasonal variations in both helium and oxygen are consistent with a circulation pattern in the thermosphere which has air rising near the summer pole and transporting air rich in helium and oxygen to the winter pole.[16, 17, 18, 19]

SYMMETRICAL SEMIANNUAL COMPONENTS

The latitudinal profile of the amplitude of the semiannual variation is illustrated in Figure 3. The amplitudes are quite small and are believed to be accurate to no more than 5 or 10%. Nevertheless, the fact that the phase of the variation was independently determined for each gas to be mid-April (or mid-October) leads to some confidence that the semiannual effect has indeed been detected. Furthermore, the latitudinal variations of the amplitudes show a systematic trend from nitrogen to oxygen to helium. The oxygen amplitude shows only a slight variation with latitude, consistent with J65. The increase of N_2 densities toward the poles (and presumably temperature) combined with the relative depletion of oxygen and helium is qualitatively consistent with dynamical models.[19] The importance of the composition is also in line with the recently revised Jacchia model[20] which represents the semiannual effect in terms of density rather than temperature variations.

SUMMARY

The analysis of composition measurements made with the neutral mass spectrometer aboard the OGO-6 satellite leads to the following conclusions. The measured atomic oxygen densities are generally in good agreement with those deduced from drag. The molecular nitrogen densities in the annual and semiannual variations depart significantly from those predicted by drag models and suggest similar departures for exospheric temperatures. The helium densities generally tend to vary in an inverse manner to the nitrogen densities. These composition changes are consistent with dynamical processes associated with the global circulation in the thermosphere.

ACKNOWLEDGMENTS

We are indebted to the many people in the Space Physics Research Laboratory of the University of Michigan, particularly W. H. Pinkus and D. R. Taeusch, and in the Laboratory for Planetary Atmospheres of the Goddard Space Flight Center, particularly D. N. Harpold and J. E. Cooley, who contributed to the success of this experiment.

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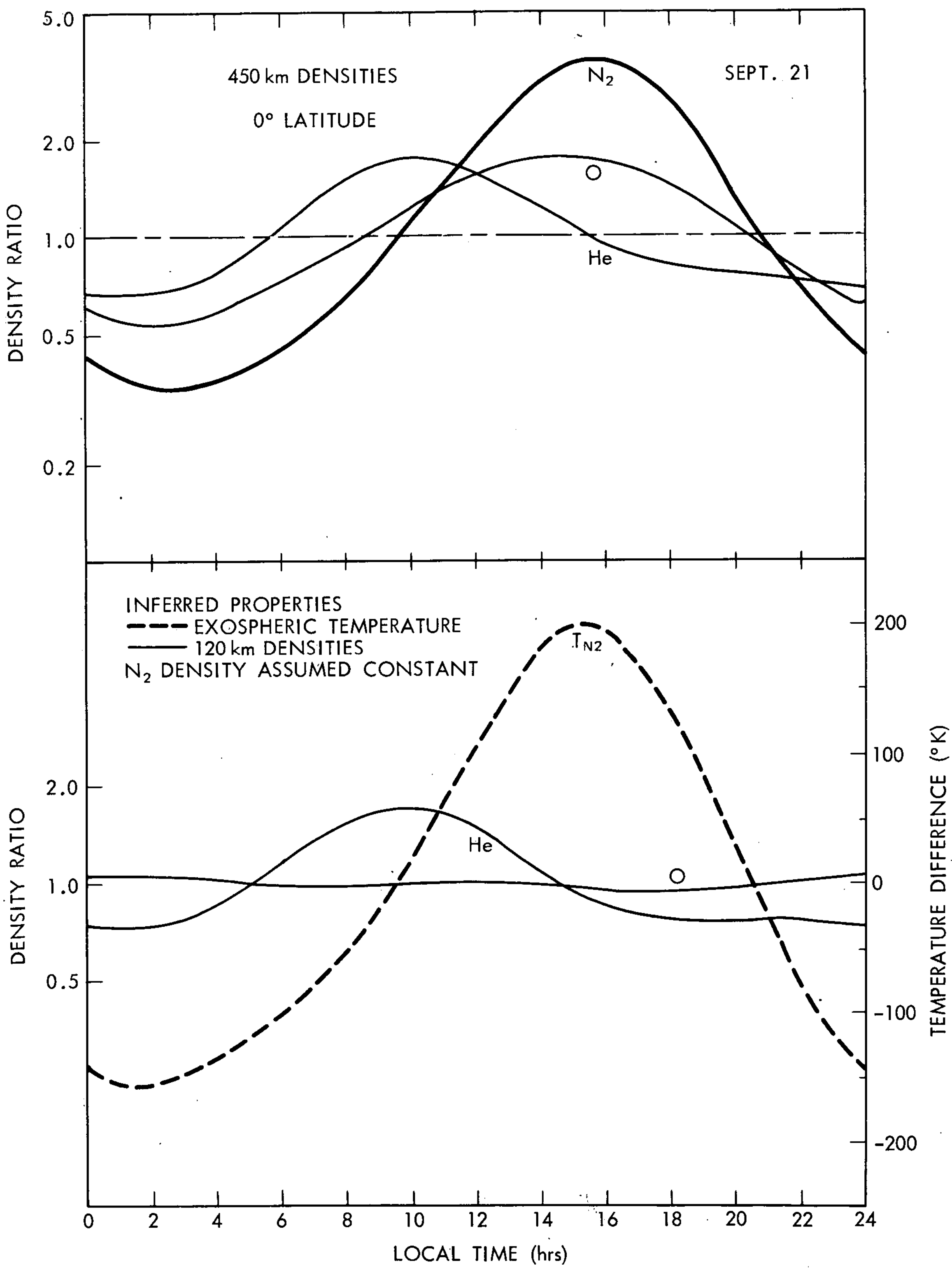
FIGURE CAPTIONS

1. Diurnal and semidiurnal components of density and temperature variation from the OGO-6 empirical density model for the equator at equinox.

2. Asymmetrical annual component of density and temperature variation from the OGO-6 empirical density model for solstice conditions.

3. Symmetrical semiannual component of density and temperature variation from the OGO-6 empirical density model.



450 km DENSITIES
0° LATITUDE
SEPT. 21
N2
O
He
DENSITY RATIO
5.0
2.0
1.0
0.5
0.2
INFERRED PROPERTIES
EXOSPHERIC TEMPERATURE
120 km DENSITIES
N2 DENSITY ASSUMED CONSTANT
TN2
He
O
2.0
1.0
0.5
DENSITY RATIO
200
100
0
-100
-200
TEMPERATURE DIFFERENCE (°K)
0
2
4
6
8
10
12
14
16
18
20
22
24
LOCAL TIME (hrs)

Figure 1.

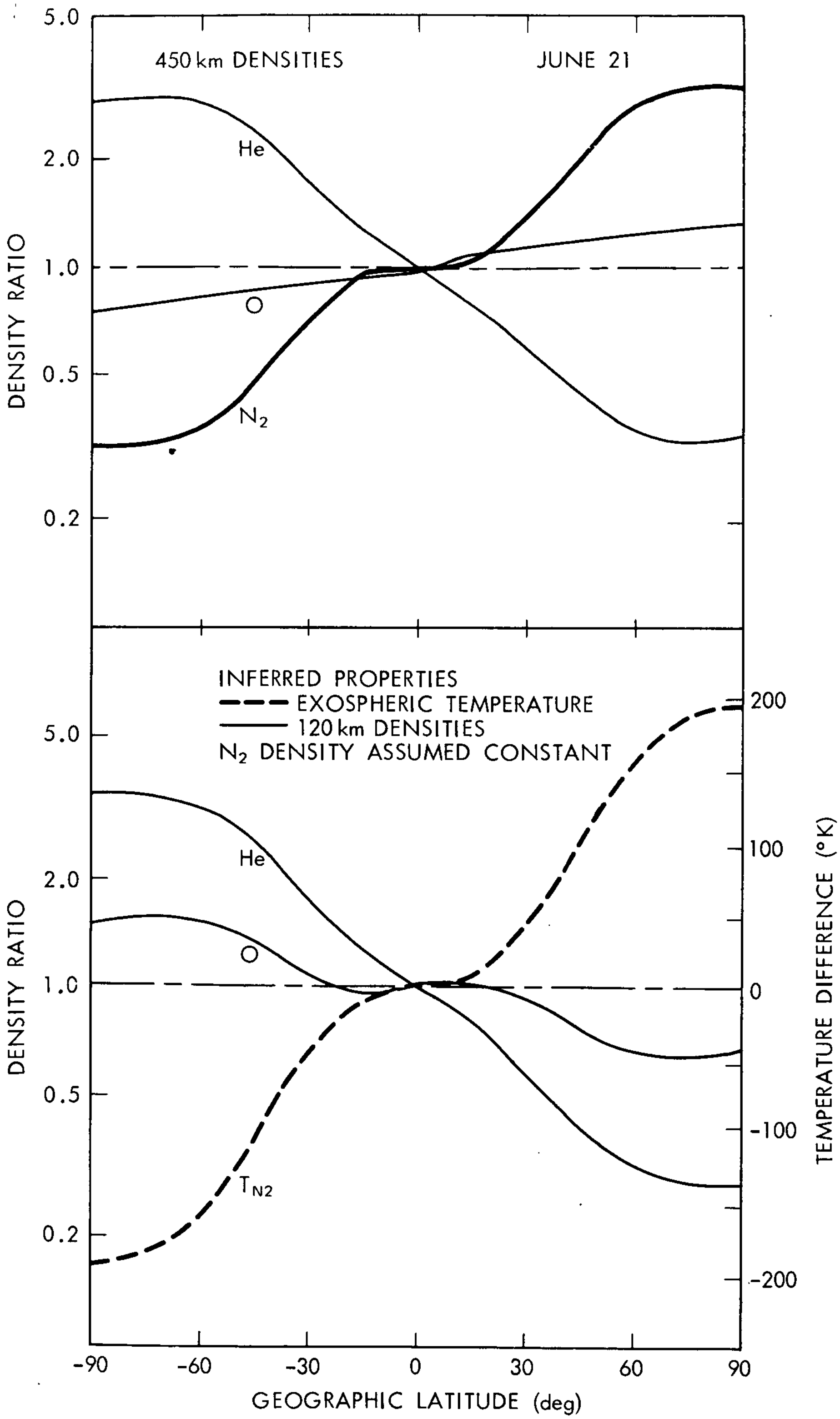

450 km DENSITIES
JUNE 21
He
O
N2
DENSITY RATIO
INFERRED PROPERTIES
EXOSPHERIC TEMPERATURE
120 km DENSITIES
N2 DENSITY ASSUMED CONSTANT
T N2
TEMPERATURE DIFFERENCE (°K)
GEOGRAPHIC LATITUDE (deg)

Figure 2.

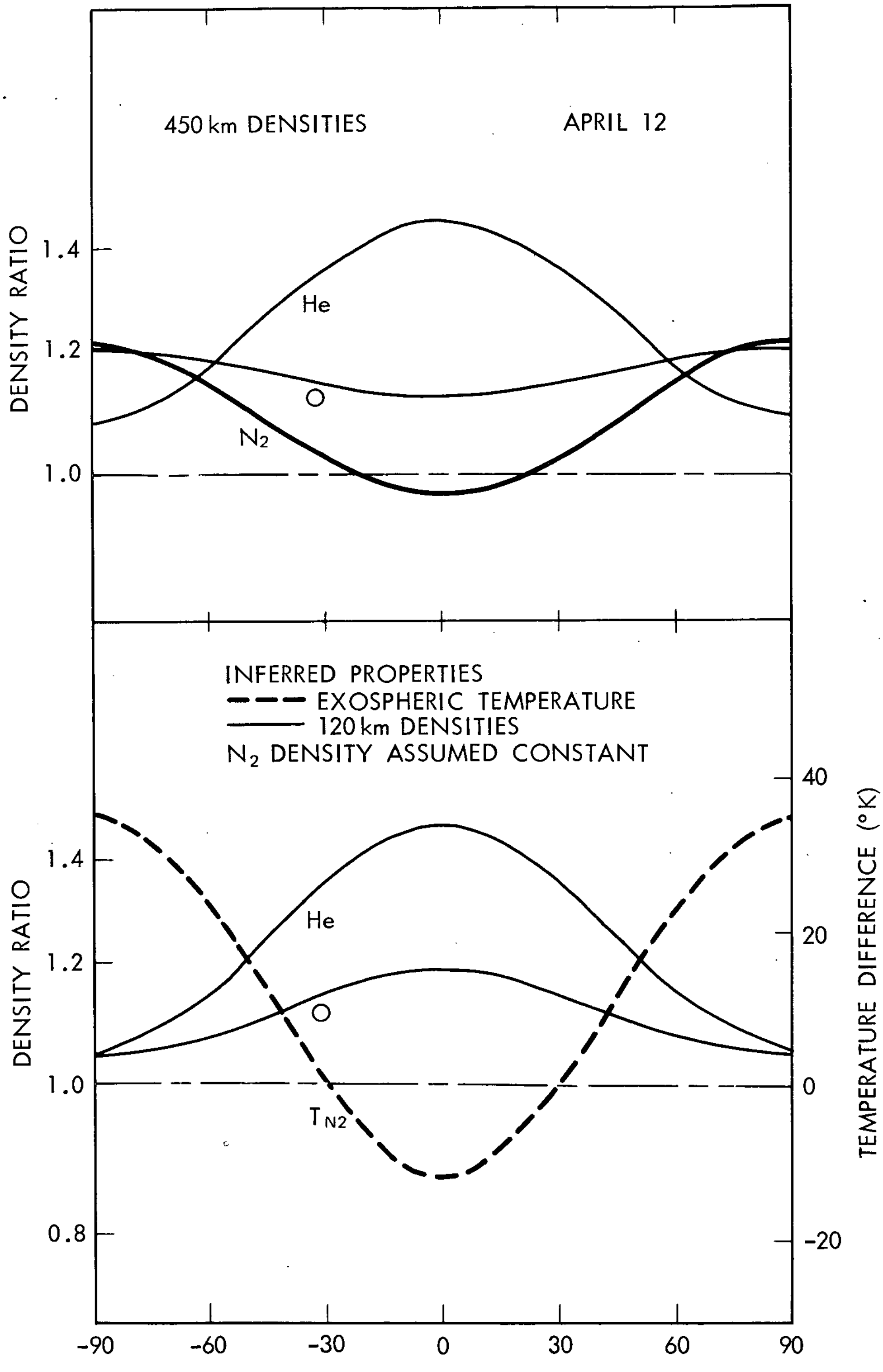


Figure 3.

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